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The impact of energy prices on the volatility of ethanol prices and the role of gasoline emissions

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ABSTRACT

The contribution of Renewable Energy Resources is vital for a country's economic growth by providing high efficiency in energy, as well as an effective tool for the confrontation of climate change. In particular, concerning the EU, an increase in the consumption of Renewable Energy Resources as a proportion of the total energy consumption by its member states was set as an objective until 2020. Ethanol has been widely used as a substitute to conventional energy like gasoline and oil. The present paper surveys the role of alternative energy prices and gas emissions in the formation of the ethanol prices. The results of the empirical survey confirmed the existence of a sole relationship among the variables employed. According to the results obtained, an increase in the volume of emissions or in gasoline prices results in an increase in ethanol prices while the opposite is confirmed in the case of crude oil. The elasticity of ethanol prices to the increase of the emissions is another result worth mentioning, indicative of the significant role of the emissions in the formation of ethanol prices.

Contents

1. Introduction

The formation of energy prices and generally the dynamics of energy markets and their interlinkages have been a subject of study within the last few decades. Different methodologies employed on different data with conflicting results can be found in the recent research. Oil is one of the most significant source in the production, while in most cases is considered as a determinant factor of alternative energy prices like gasoline, coal, electricity and others [1–5].

Biofuels are an alternative energy source extensively used in the World War II as emergency fuel in a number of European countries. As soon as the conditions ceased to exist, the conventional energy sources have started to be used again extensively [6]. In order for the EU to realize the goals set for the year 2010 and beyond, current measures aiming to increase biofuel consumption will have to become more intense [7].

Recently, the production of biofuel has increased globally due to increasing energy demands and the widespread debates concerning the environment. Thus, an extensive use of biofuels has been recorded

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in many countries, while many others are now taking steps in the same direction [8].

Furthermore, many governments support biofuel production as a substitute for petrol and diesel through subsidy programs and relevant decisions, based on the argument that this will reduce their countries' dependence on fossil fuel and simultaneously to have a positive impact on the climate [9].

The global energy crisis along with constant hike observed in fossil fuel prices motivated mankind to look for new, alternative energy sources. Biodiesel and bioethanol are two new, clean energy sources that can replace oil. Thus, countries like Taiwan promoted the cultivation of energy plants for the production of bioethanol [10].

The advantages linked to biofuel use, as opposed to fossil fuels, have been promoted by the European Union for a number of years, including (a) a reduced dependency on energy imported from abroad, along with the use of raw materials that can be produced in the EU, (b) fuel price stability, as opposed to volatile fossil fuel prices, (c) a reduction in CO_2 emissions, since the raw materials used for biofuel production capture CO_2 from the atmosphere, and finally, (d) a benefit to the primary sector from biofuel consumption, due to the use of agricultural products as raw materials [11].

The need for biofuels in transportation, particularly in liquid form, such as ethanol and biodiesel, has been felt by many countries, whose governments are trying to promote such fuel. Compared to oil, the use of biofuels in the transportation sector is still relatively limited. At the moment, the highest levels of ethanol production and consumption are recorded for US and Brazil [12].

Liquid biofuel is one of the few substitutes for fossil fuel, not only in the short- but also in a middle-term basis, and for this reason it is promoted by the European Union as a transportation fuel (like ethanol); it also contributes to limitation in environmental problems, like global warming. To be more specific, the phenomenon of global warming interacts in a negative way with ethanol when derived from poplar biomass [13].

The global emergence of biofuels production has brought about major changes, both to the liquid fuel market, and to the demand for the relevant food products used. Various research papers have attempted to define the economic nature of this event, by evaluating, inter alia, the impact of the ethanol industry's growth on economic welfare [14,15].

Due to rapid population increase and industrialization, the global demand for ethanol is constantly on the rise. Conventional crops, such as corn and sugar cane, are difficult to satisfy the global demand for bioethanol production, given their extensive primary use as food and feed. For this reason, lignocellulosic materials, such as agricultural wastes, are raw materials for the production of bioethanol. Agricultural residues are another low cost option, as being a renewable source and in abundance. Bioethanol production from agricultural waste necessitates a highly promising technology, although the particular process implies various challenges and restrictions [16].

The production of fuel ethanol from renewable lignocellulosic materials (bioethanol) may well reduce dependence on oil globally, achieving at the same time a reduction in net carbon dioxide emissions [17].

In the past, the world biofuel production was approximately 58 million kl, which corresponds to about 1.3% of the global oil consumption. During the third quarter of 2008, ethanol production exceeded 19,766 kbbl (kilobarrels), almost 14 times higher than that of the same quarter in 1986 [18].

The size of the ethanol market has increased from about 1.2 billion gal in 1997 to approximately 5 billion gal in 2006. Due to the huge increase in demand for ethanol in recent years caused by the increased supply of corn, the prices of numerous foods have risen steeply [19].

Despite the fact that bioethanol is available commercially all around the world, it is not produced so extensively in EU. In EU-27, 2800 ML was produced in 2008, with France being in the top position with a remarkable increase from 2005 to 2008 (144 and 950 ML, respectively). Spain has maintained an almost stable production level, while Germany, Hungary and Poland have presented a steadily positive trend in their production. In the remaining 27 countries, the production level has either remained stable or decreased (Sweden) [20].

In Europe today, the most common first generation biofuel is biodiesel, produced from sunflower or rapeseeds, and bioethanol, produced from corn, grains or sugar cane. Both methods have been fully commercialized today, since the resulting products are being exploited by private investors in several cases [21].

In 2007, the total contribution of biomass to primary energy consumption in the EU was 89 million ton of oil equivalent. The main share (66.4 Mtoe) was solid biomass and the rest was biogas, biofuel for transport and renewable urban solid waste [20].

At the moment, the main crops used in Europe for the production of bioethanol are grains (70% in 2008), and sugar cane to a much lesser degree. Sweet sorghum is considered to be a good choice for the future, particularly in Mediterranean regions; however a series of issues need to be settled, particularly as regards the supply chain [20].

In Europe, the directive for the promotion of energy use from renewable energy sources aims at a share of 20% – including bioenergy – of the total energy consumption in 2020 and also imposes a share of 10% at least, as regards the use of renewable energy sources in transport, where biofuel is expected to play a major role. In 2007, the share of biofuel in the total fuel consumption in the EU was 2.6%, which corresponds to a combined estimate of ethanol and biodiesel consumption of 9.9 billion litre. Thus, great efforts need to be made in order to reach the goal of 10% by 2020, which will correspond to an approximate biofuel use of 22.8 billion litre [22].

The policies aiming at the promotion of biofuels at a local level have had a huge impact on global market developments during the last decade. The global production and trading in biofuels have risen steeply: from under 30 PJ in 2000 to 572 PJ in 2009, for biodiesel production, and from 340 PJ in 2000 to over 1540 PJ in 2009, for fuel ethanol production. The EU has globally dominated the production of biodiesel, while the US and Brazil are first in the production of fuel ethanol. Import duties largely affect the volume of trade, as well as tariff preferences [23].

The use of biofuel is having a major effect on land use changes and the exploitation of wastelands. In India, there is great interest in biofuels, as a substitute for oil, aiming to strengthen energy security and promote agricultural growth. India has announced an ambitious plan to replace 20% of fossil fuels consumption with biodiesel and bioethanol by 2017. In addition, it has presented a national policy for biofuel and has begun an extensive program for the promotion of biofuel production, particularly on wastelands [24]. Forest tree plantations and forest residues play another equally important role in ethanol production [25].

In Brazil, the demand characteristics of ethanol have been a subject of a study, within the context of differentiating the fuel mix. Actually, nowadays ethanol is the most important gasoline additive and alternative fuel consumed in Brazil, and a determinant of changes observed in fuel consumption. The diffusion of flex-fuel vehicles in Brazil marks a new stage in this expansion and ethanol is a central component of the increasing demand for fuel. In order to evaluate the demand for ethanol in Brazil, after the introduction of flex-fuel vehicles, a cointegration approach was used and autoregressive distributed lag bounds tests were employed over the period 2003–2010. The results confirm that during the last decade, ethanol has significantly strengthened its

position, both as an independent fuel and as a substitute for gasoline. There are also indications that the development of an automobile fleet based on the flex-fuel technology contributes to a long-term demand for ethanol [26].

Moreover, the import of flex-fuel vehicle technologies in Brazil has provided consumers with the opportunity to choose among various types of fuels, according to fuel prices. Bioethanol is in general the most cost-effective type of fuel, not only in Brazil but also in other countries [27].

Brazil has developed an integrated program for biofuel in the world, introduced along with the oil crisis of the 1970s. In 1975, Brazil introduced the National Programme *Proalcool*, focused on the production of ethanol from sugar cane. Its aim was to estimate in monetary terms the surplus production of sugar cane and achieve the energy supply of the market [28]. At the same time, the government also signed certain agreements with manufacturers, in order to develop a market for specially modified vehicles, that will consume a mix of bioethanol and gasoline [29].

The US and Brazil use different raw materials for ethanol production. To be more specific, Brazilian ethanol is based on sugar cane production, while the US on corn. It is well known that the production of ethanol from sugar cane is more cost-effective than corn, and for this reason the US imposed tariffs on ethanol imports (0.54 dollars/gal) in order to protect their domestic ethanol market [30].

Following the oil crises of the 1970s, a renewed interest in alternative fuel sources came up. Developed countries realized their dependence on fossil fuel imports. Despite the variety of policy measures adopted, it is very difficult to displace conventional fuel. In Europe, the main medium used to promote biofuel is a tax exemption, through the implementation of Directive 2003 (2003/30/EC) regarding biofuel [6].

Within this changing environment the survey of energy market including renewable and conventional energy sources may be of great interest, given the fact that the introduction of biofuels has strengthened linkages between fuel and corn markets.

An objective of this paper is to confirm a decline in fuel prices as a result of the supply expansion resulting from the introduction of biofuels.

For the particular survey the methodology of the Johansen cointegration technique was employed while for the interaction of the energy prices formation the impulse response analysis was employed. The present paper is organized as follows.

The next section provides a brief description of the existing literature, Section 3 describes the methodology and the data employed, Section 4 presents the results of the methodology while Section 5 presents the conclusions.

2. Literature review

The main driving forces for bioenergy trading are fossil fuels prices (mainly oil prices), and the policy for reducing the emissions of greenhouse gases [31].

Due to their social and political significance, the relation between energy prices and the prices of agricultural products has become extremely important. Although the correlation between these two groups of product prices has been historically low [32], the largest part of the research has proven that the development of the ethanol industry has strengthened the linkages between food and energy prices [14,19,33].

Despite the increasing importance of biofuels, its effect on the fossil fuels market is not yet clear. Thus, they developed a joint structural Vector Auto Regression (VAR) model of the global crude oil, US gasoline, and US ethanol markets, in order to examine the extent to which the US ethanol market has affected global oil markets. The researcher observed that despite the small size of the ethanol market in the US, the effects of the relevant US policy on the crude oil market are diffuse [34].

The development of the ethanol industry affects the relation between food and energy prices. The researchers with the assistance of a stochastic equilibrium model reached the conclusion that the ethanol markets have caused both an increase and volatility in corn prices [33].

High crude oil prices have also contributed to the increased demand for ethanol. More recently however, the drop in oil prices along with the global economic crisis has undermined investments in ethanol projects [35]. Other researchers have observed that the crude oil prices have an indirect effect on food prices [36].

Brazil is today the greatest producer of ethanol from sugar cane worldwide. In Brazil, the ethanol industry was initially supported by the *Proalcool* project, which was the political answer to the lack of gasoline during the oil crisis of 1973 [37], and promoted both the supply and demand for ethanol. Since the year 2000, a remarkable increase in the demand for ethanol fuel has been observed. The rise in oil prices, the efforts to protect the environment and the planet's climate, the interests in energy differentiation and security, all render ethanol an attractive alternative, particularly for industrial countries. In developing countries, attention is rather focused on rural development, creating employment, cost savings and improvement on access to energy markets [38].

Other researchers studied the impact of international oil prices on the markets for bioethanol and corn in the US. Based on their research, they confirmed that a rise in oil prices globally increases the demand for bioethanol from corn, as well as the price of corn on a short-term basis, which is then stabilized in the long-term [18].

The recent increase in ethanol use in the US reinforces and changes the nature of the relation between agricultural products and energy markets. It has been observed, that the ethanol producers' prices are more sensitive to corn yields, rather than oil prices [36]. Market developments and policy changes have repeatedly strengthened the relation between energy and agricultural markets, but also changed its nature. It has been observed historically, that the price of oil affects agricultural production, as well as the transport and processing of agricultural products [39].

Other researchers in a recent study, using nonlinear causality analysis showed that there are non-linear feedbacks between oil prices and the prices of agricultural products [40].

In addition, the agricultural sector, which plays a major role in the development of ethanol production, is shown to offer significant benefits to farmers; this could be a way of reducing the cost of agricultural products and market distortions which are linked to existing agricultural support policies, estimated as amounting to $320 billion/year, only for the countries of the OECD [38].

Other researchers using a smooth transition vector error correction model, proved that there is a long-term relation between the prices of ethanol, oil and corn, which means that strong linkages are identified between energy and food prices [41].

In addition, there is also another parameter connecting the agricultural sector to oil prices. More specifically, energy-intensive crops are vulnerable to oil price fluctuations, due to the fact that their producers have to pay significant sums for supplies (fertilizers, fuel, electrical energy), and the prices paid by the farmers for oil products or direct energy reflect the national energy markets. In addition, most farmers–producers purchase energy indirectly from other sources, such as nitrogenous fertilizers, fuel and electrical energy, in order to operate their farms [36].

What also has to be mentioned is the role of policy parameters on the formation of the energy prices as well as their interlinkages and the pattern of price adjustments. Other equally important

factors that may well affect the existing situation are related to rigidities, transaction costs, adjustment costs, market power, or risk on ethanol markets.

The literature concerning a quantitative analysis on the relationships between crude oil prices, ethanol prices and gasoline prices is extremely limited. Though, there are a few that are worth mentioning. To be more specific, [42] O'Brien and Woolverton (2009) examined the statistical relationship between the ethanol prices and the gasoline prices and found a positive correlation between the ethanol price series and the oil price series approaching 83%.

Furthermore based on the findings of Ref. [42] a 10% increase in the Midwest gasoline prices brought about a 6.59% increase in the Iowa ethanol prices. Their analysis refers to the period 2007–2009. In another study [44] a strong positive correlation between the ethanol and gasoline prices was also confirmed. Furthermore in Ref. [45] with the assistance of the non-spatial multi-market partial equilibrium international ethanol model the price linkage between the ethanol and gasoline markets was analyzed for the United States, Brazil, and European Union. An issue on which they focused is related to the substitution and complementarity relationship between the two fuels; and according to their results, ethanol is mainly used as an additive to gasoline while the complementarity relationship is considered to be more dominant than the substitution relationship between ethanol and gasoline in the US. In another study [46], the wholesale gasoline price along with the federal subsidy level found to have a significant effect on the ethanol price.

In Ref. [47] an analysis in order to survey statistical relationship between ethanol, gasoline and crude oil prices on EU was made. Their results provide evidence of the co-integration relationship between the oil and gasoline prices, but no co-integration between ethanol, gasoline and ethanol, oil prices was confirmed. In addition, after estimating a VAR model, they confirmed a relationship between the price of gasoline and ethanol, gasoline and oil prices, oil price and ethanol price; while according to their findings, the strongest is the relationship observed between the oil prices and gasoline prices. Finally the impulse response analysis they conducted confirmed that the impact of the oil price shock on the other variables is considerably larger than vice versa while the largest impact of the oil price shock was observed on the price of gasoline and confirmed a temporary response.

Having in mind the special conditions for the trade of ethanol, and the interactions of different energy sources it is quite interesting to survey how price shocks are transmitted from one energy source to the other. Actually, the degree of transmission can have important implications for pricing practices and policy, and can allow a better understanding of the overall functioning of the market.

3. Data and methodology

3.1. Data

The data used in the present study are monthly seasonally adjusted prices of crude oil, gasoline, ethanol and the volume of gas emissions (GHG emissions). Ethanol, oil and gasoline prices are in dollars per gallon, while the gas emissions are in m^3. The energy prices refer to the time period from January 2006 until June of 2010 and are mean prices for EU. The limited reference period is related to lack of data for the price of ethanol. The particular prices were derived by the Bloomberg database for the region of European Union, with exception of the volume of GHG emissions that was derived by Eurostat. All the values are expressed in the logarithmic form.

Figs. 1–4 plot the price series used in the empirical survey. To be more specific, Fig. 1 illustrates the evolution of crude oil.

The prices of crude oil are characterized by a significant peak in the year 2008 and a significant decrease in the middle of the year

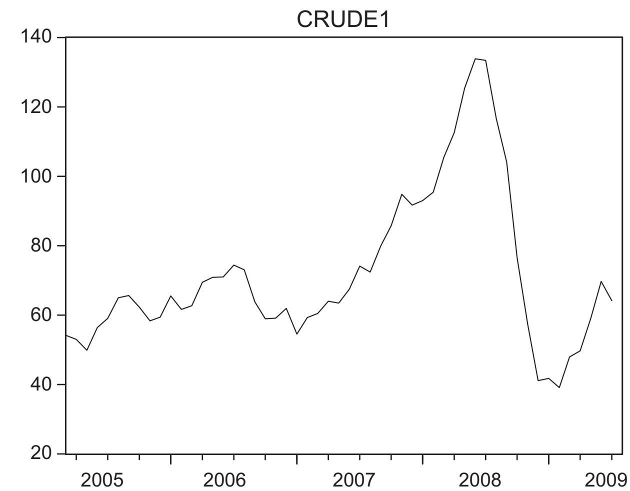

Fig. 1. Evolution of crude oil prices.

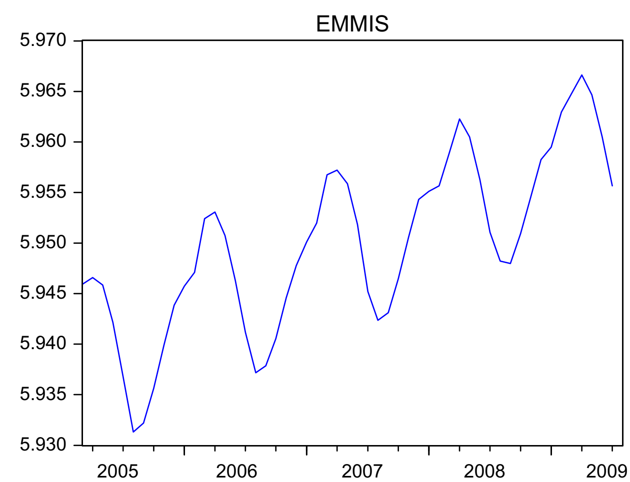

Fig. 2. The evolution of gasoline emissions.

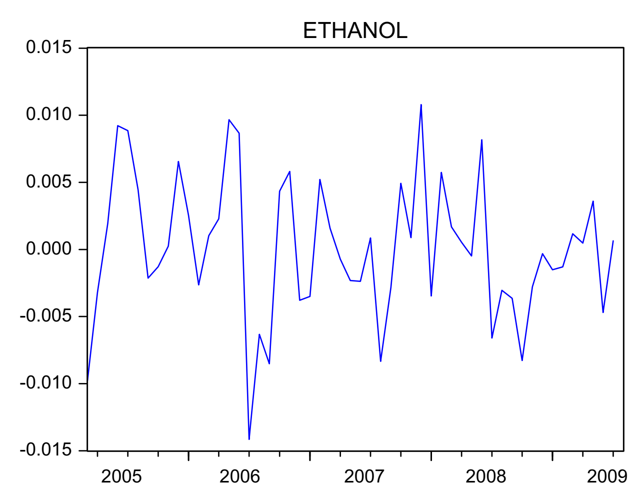

Fig. 3. The evolution of ethanol prices.

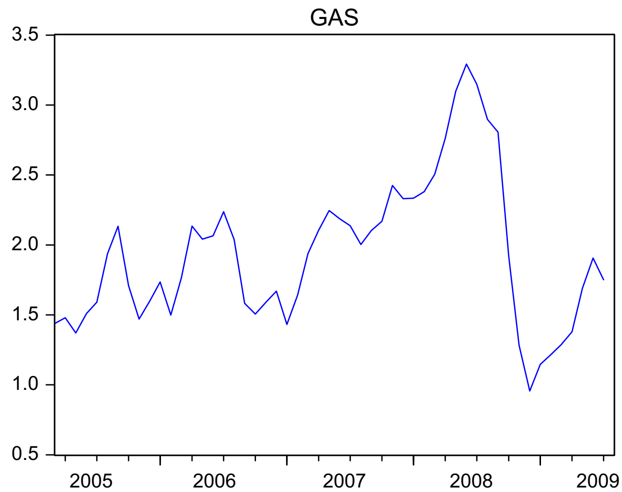

Fig. 4. The evolution of gasoline prices.

2008. Thus year 2008 is characterized by significant volatility in the crude oil prices.

In Fig. 2, it is evident that the emissions despite the volatility show a significant increasing trend. The evolution of gas emissions is not in compliance with the crude oil prices volatility.

Maybe the greatest volatility of all within a small range is evident for the ethanol prices. Though, there seems to be an equilibrium price to which ethanol price returns after a particular shock. Additionally, a significant low value and with negative sign is evident for the observation of May of the year 2006.

Last but certainly not the least is the evolution of the gasoline prices, the volatility of which is evident while the crude oil prices and the gasoline prices present a similar volatility pattern.

Having in mind the function of energy market it would be interesting to survey the role of the gas emissions on the formation of the renewable and conventional energy prices. The additional data processing would include unit root test in order to survey whether the employed variables are either I(1) or I(0) in order to be able to implement the cointegration test.

3.2. Methodology

The volatility and the behavior of energy prices (crude oil, gasoline, and ethanol) and the role of gas emissions were surveyed with the application of the Johansen cointegration technique. A pre-condition for the application of this method is to survey whether the time series are I(1). This means that the time series studied are non-stationary in levels and stationary in first differences. Stationarity for those time series was surveyed with the application of the ADF unit root test [43]. The ADF test has been widely used for testing the existence of a unit root in the time series studied.

The particular test aims at testing the null hypothesis for a single unit root in the data-generating process for any variable surveyed. In order to determine the ADF form we used the Akaike and the Schwarz–Bayesian (SBC) criterion. For every time series we chose the model, for which the Akaike and SBC criterion has the lowest value. According to the results of this process we determined the final form of the auxiliary regression that includes a constant and a time trend for all the variables employed.

Through this test we concluded that the time series examined are either I(1) or I(0) and consequently their combination can be tested for stationarity with the application of the Johansen cointegration technique. Though, the power of this test was in many cases in doubt. A simple modification of the ADF test referred to as the DF-GLS test was suggested in Ref. [47]. The DF-GLS test is shown to be approximately uniformly most power invariant (UMPI) while no strictly UMPI test exists. Monte Carlo simulation results have indicated that the power improvement from using the modified the Dickey–Fuller test can be large. The same results were derived by the particular methodology though.

Given that the time series studied are I(1), according to the results of the stationarity tests we can use the Johansen technique to examine whether there is a combination (linear relation) of the variables that is stationary. In this case the variables studied are cointegrated and hence, there is a long-run relationship between them.

As it was already mentioned above, the cointegration technique can be applied to the time series employed given that they are non-stationary in levels and stationary in first differences. The Johansen cointegration technique as described in Refs. [48,49], involves testing the null hypothesis that there is no cointegration against the alternative that there is cointegration. The method uses two likelihood ratio (LR) test statistics – namely, the trace and the maximal eigenvalue (A-max) statistics – to test for the number of cointegrating vectors in the non-stationary time series. The critical values are taken from Ref. [50], which differ slightly from those reported in Ref. [51]. In order to apply the Johansen technique it is necessary to calculate the number of lags of the endogenous variables of the model since an autoregressive coefficient is used in modeling of each variable. The determination of the number of lags depended on the Akaike information criterion and the Ljung–Box test.

Based on the Granger representation theorem according to which, if a cointegrating relationship exists among a set of I(1) series, a dynamic error-correction (EC) representation of the data also exists.

Thus, in the second stage we estimated the Vector Error Correction Model in order to examine the direction of the causality between the four variables employed. The direction of the causality is determined by the statistical significance of the cointegrating equation coefficient. Additionally, the error correction model captures not only the long-term but also the short-term dynamics of the model.

Finally, we conducted an impulse response analysis of the variables studied. The generalized impulse responses as described in Refs. [52,53] provide a tool for describing the dynamics in a time series model by mapping out the reaction in the ethanol price for instance to a one standard deviation shock to the residual in the other three aforementioned variables.

The VAR process we consider is the following:

$$x_t = \Phi D_t + \sum_{i=1}^{k} \Pi_i x_{t-i} + \varepsilon_t, \quad t = 1, 2, \ldots, T \tag{1}$$

The process x_t representing the vector of prices is covariance stationary, integrated of order d (and possibly cointegrated), while ε_t is p dimensional and assumed to be identically, independently, distributed (i.i.d.) with zero mean and positive definite covariance matrix Ω.

The h-ahead forecast error for the x_t process is given by the following equation:

$$x_{t+h} - E[x_{t+h}/I] = \sum_{j=0}^{h-1} C_j \varepsilon_{t+h-j} \tag{2}$$

where I is an information set which includes the history of x_s up to and including period t as well as the entire time path for D_t. The $p \times p$ matrices C_j are given by $C_0 = Ip$ and

$$C_j = \sum_{i=1}^{\min k,j} \Pi_i C_{j-i}, \quad j \geq 1 \tag{3}$$

Table 1
Results of ADF unit root test.

Variables	DF-GLS test	ADF test
$p_{crudeoil}$	−2.367586	−3.267375
$\Delta p_{crudeoils}$	−3.640914	
$p_{gasoline}$	−2.803562	−2.790335
$\Delta p_{gasoline}$	−4.596229	−4.504274
$p_{ethanol}$	−3.988649	−6.189838
$p_{emission}$	0.032648	−0.413544
$\Delta p_{emission}$	−8.102956	−7.724969

Notes: The critical values for the ADF test and for 1%, 5% and 10% significance values are −4.198503, −3.523623, −3.192902 for the variables in levels and −4.192337, −3.520787, −3.191277 in first differences respectively.

Table 2
Results of the Johansen cointegration test with trace statistic.

Null hypothesis	Trace statistic	5% Critical value
$r=0$	79.23034	62.99
$r\le 1$	40.51745	42.44
$r\le 2$	15.82815	25.32
$r\le 3$	4.179609	12.25

Table 3
Results of the Johansen cointegration test with maximum eigenvalue statistic.

Null hypothesis	Maximum eigenvalue statistic	5% Critical value
$r=0$	38.71289	31.46
$r\le 1$	24.68929	25.54
$r\le 2$	11.64854	18.96
$r\le 3$	4.179609	12.25

so that all C_j matrices can be determined recursively from the Π_i matrices.

In Ref. [52], the generalized impulse response function was by the following equation:

$$GI_x(h,\delta,I_{t-1})=E[x_{t+h}/\varepsilon_t=\delta,I_{t-1}]-E[x_{t+h}/I_{t-1}] \quad (4)$$

where δ is some known vector. For the VAR process this means that

$$GI_x(h,\delta,I_{t-1})=G_h\delta \quad (5)$$

The choice of δ is therefore central to determining the time profile for any generalized impulse response function. As an alternative to shocking all elements of ε_t one may consider just shocking one element such that $\varepsilon_{jt}=\delta_j$. We may now define the generalized impulse responses as

$$GI_x(h,\delta_j,I_{t-1})=E[x_{t+h}/\varepsilon_{jt}=\delta_j,I_{t-1}]-E[x_{t+h}/I_{t-1}] \quad (6)$$

Letting $\delta_j=(\omega_{jj})^{1/2}$, the standard deviation of ε_{jt}, and assuming that ε_t is Gaussian, it follows that

$$E[\varepsilon_t/\varepsilon_{jt}=\sqrt{\omega_{jj}}]=\Omega e_j\omega_{jj}^{-1/2} \quad (7)$$

where e_j is the jth column of Ip. For the VAR model we then find that

$$GI_x(h,\sqrt{\omega_{jj}},I_{t-1})=C_h\Omega e_j\omega_{jj}^{-(1/2)} \quad (8)$$

This measures the response in x_th from a one standard deviation shock to ε_{jt}, where the correlation between ε_{jt} and ε_{it} is taken into account. Defining the diagonal $p\times p$ matrix Σ as

Table 4
Estimation of the error correction model.

Error correction	D(CRUDE1)	D(EMMIS)	D(ETHANOL)	D(GAS)
CointEq1	0.077318	−0.000101	0.000228	0.005818
	[0.78912]	[−3.28055]	[2.51009]	[1.88578]
D(CRUDE1(−1))	0.582098	6.73E−05	0.000177	0.000739
	[2.11212]	[0.78007]	[0.68944]	[0.08510]
D(CRUDE1(−2))	0.630785	8.52E−05	−0.000283	0.030676
	[1.88273]	[0.81239]	[−0.91044]	[2.90770]
D(CRUDE1(−3))	−0.021578	3.72E−05	0.000551	0.003142
	(0.29863)	(9.4E−05)	(0.00028)	(0.00940)
D(CRUDE1(−4))	−0.711051	9.95E−05	−0.000235	−0.016940
	[−2.70488]	[1.20849]	[−0.96231]	[−2.04649]
D(EMMIS(−1))	845.7888	0.912547	0.100322	6.947859
	(491.106)	(0.15381)	(0.45624)	(15.4643)
	[1.72221]	[5.93293]	[0.21989]	[0.44928]
D(EMMIS(−2))	−574.3034	0.061376	−1.021226	−4.479646
	[−0.66362]	[0.22645]	[−1.27023]	[−0.16439]
D(EMMIS(−3))	253.8469	−0.048828	1.059605	−18.17584
	[0.34658]	[−0.21286]	[1.55726]	[−0.78808]
D(EMMIS(−4))	−107.3408	0.298004	−1.822781	6.380940
	[−0.18779]	[1.66467]	[−3.43271]	[0.35453]
D(ETHANOL(−1))	368.1725	−0.230580	−0.425116	21.45303
	[1.47539]	[−2.95030]	[−1.83378]	[2.73017]
D(ETHANOL(−2))	76.78922	−0.229428	−0.332594	15.38491
	[0.31814]	[−3.03493]	[−1.48324]	[2.02420]
D(ETHANOL(−3))	228.3130	−0.155705	−0.254028	13.52174
	[0.93651]	[−2.03925]	[−1.12162]	[1.76140]
D(ETHANOL(−4))	208.6374	−0.055523	−0.242052	10.35496
	[1.25765]	[−1.06863]	[−1.57058]	[1.98226]
D(GAS(−1))	−2.784408	−0.002912	−0.004037	0.178567
	[−0.37389]	[−1.24831]	[−0.58345]	[0.76147]
D(GAS(−2))	−5.633224	−0.006240	0.006370	−0.699513
	(8.34529)	(0.00261)	(0.00775)	(0.26278)
	[−0.67502]	[−2.38737]	[0.82162]	[−2.66194]
D(GAS(−3))	−8.960393	−0.000937	−0.011199	−0.119906
	[−1.16941]	[−0.39051]	[−1.57327]	[−0.49697]
D(GAS(−4))	24.32787	−0.007386	0.002235	0.401037
	[3.25768]	[−3.15785]	[0.32222]	[1.70543]
C	−0.273158	−8.91E-05	0.000415	0.005890
	[−0.32226]	[−0.33572]	[0.52687]	[0.22068]
R-squared	0.739898	0.846654	0.682819	0.743247
Adj. R-squared	0.592507	0.759758	0.503084	0.597753

Table 5
The residuals of the VECM.

Test	Qstat	LM_2	LM_4	Lutkepohl–Jarque–Bera	White heteroskedasticity
Statistics	13.0588	16.18	14.18	28,308	34,775
P	0.1322	0.3982	0.585	0.004	0.3743

$$\Sigma=\begin{bmatrix}(e_1'\Omega e_1)^{-1/2}\\(e_2'\Omega e_2)^{-1/2}\\(e_3'\Omega e_3)^{-1/2}\\\dots\\(e_p'\Omega e_p)-1/2\end{bmatrix} \quad (9)$$

we may express the generalized impulse responses in matrix form as

$$GI_x(h,\sqrt{\omega_{11}},\dots,\sqrt{\omega_{pp}},I_{t-1})=C_h\Omega\Sigma=C_hB=A_h \quad (10)$$

where column j is given by $GI_x(h,\sqrt{\omega_{jj}},I_t)$, I_{t-1}. When Ω is diagonal, then $B^*\Omega^{1/2*}\Sigma^{-1}$ is a diagonal matrix with standard deviations along the diagonal.

4. Results

The implementation of stationarity tests confirmed the existence of a unit root in gasoline, emission and crude oil prices while on the other hand the stationarity of ethanol prices was confirmed with both ADF and GLS-DF stationarity test. The results of the aforementioned tests are presented in Table 1. The next step involved the implementation of Johansen cointegration test.

Cointegration test based on trace statistic as presented in Table 2 confirms the existence of a (single) long-run relationship between ethanol, gasoline, emission and oil prices. A high degree of integration between the biofuel and the fossil fuel markets should ensure a strong price link between the aforementioned products.

The same results are derived with the maximum eigenvalue statistic (Table 3). This result implies the existence of a sole relationship among the variables employed. Our results are in line with those of Ref. [54] who confirmed the co-integrating relationship among the U.S. fuel prices (gasoline, oil and ethanol). An issue that should be stressed is that empirically in the literature this relationship was confirmed only in the ethanol boom period (2000–2007). There was no co-integrating relationship between the ethanol and oil prices before the year 2000 for the USA data. The only co-integration relationship was found between the gasoline and oil prices in the period 1989–1999. Additionally, in order to survey the short term dynamics of our model we estimated the error correction model, given that all of the variables are cointegrated. The results of the estimation are provided in Table 4.

According to the results presented above the coefficient of the cointegrating equation is significant at 5% significance level for all the variables employed with exception that of the crude oil. Regarding the residuals of the VECM as presented in Table 5, we can argue that the residuals of the model do not suffer neither from heteroskedasticity nor from autocorrelation. Furthermore the fact that the cointegrating equation is significant only in the first equation implies that the price of crude oil is not affected by the other three energy prices. This result implies that the price of crude oil is the determinant of the energy market as expected and consequently a guide for the other energy prices. In addition, the crude oil price is determined by different factors. What also must be interpreted is the role of the ethanol price, which is the renewable energy source. Concerning the ethanol price, the coefficient of the cointegrating equation is positive. This result implies that after a shock in ethanol price there is no return to the steady state but a deviation from this value.

Since our interest is focused on ethanol price the cointegrating equation with dependant variable that of ethanol price is the

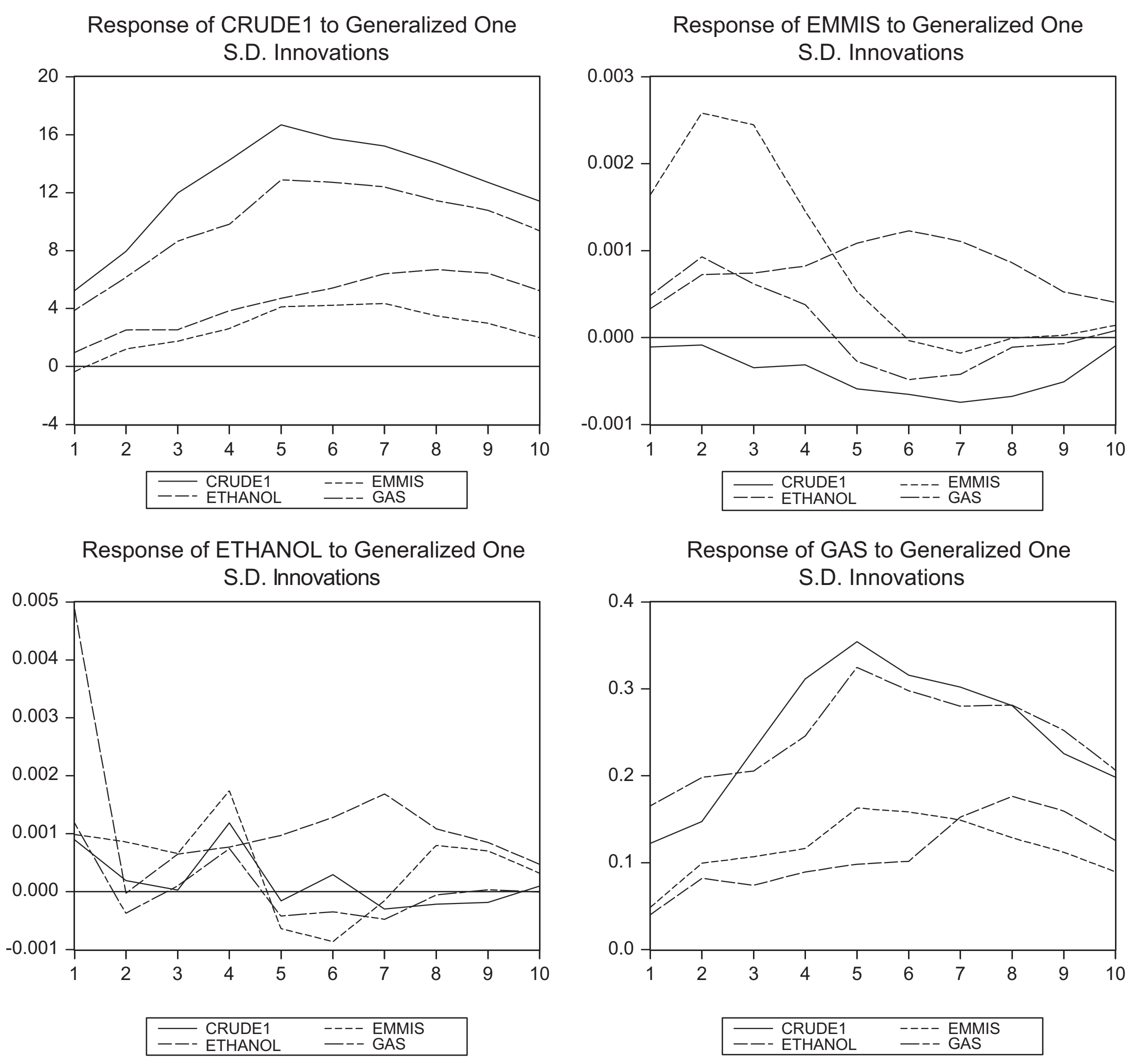

Fig. 5. Impulse response analysis for the energy market.

following:

$$\underset{(0.05)}{\text{eth} = 0.22\text{emm}} - \underset{(7\times10^{-5})}{0.000153\text{cr}} + \underset{(0.0032)}{0.0052\text{gasoline}} - \underset{(0.3)}{1,32}$$

It is evident that emissions illustrate the greatest elasticity in the cointegration equation of the ethanol prices. To be more specific an increase in the emission leads to an increase of ethanol price to an amount of 2.2%. The particular result implies that the necessity for biofuels stemming from an increase in GHG emissions affects in a significant way the price formation of ethanol. Negative sign for the coefficient of crude oil is confirmed. This result implies that an increase in the crude oil price is accompanied by a decrease in ethanol prices. On the contrary an increase in the gasoline price leads to an increase in ethanol price. Thus, the behavior of ethanol is different for an increase in two different conventional energy sources. In addition, our results contradict those suggested by the existing literature since it is argued that the literature suggests that higher fuel prices and an increase of ethanol's production are likely to reduce the supplies of food and increase food prices (used for the production of ethanol), and that fuel prices are likely to decline as a result of the supply expansion resulting from the introduction of biofuels. In addition statistically significant is the constant in the cointegration equation, a result that implies the existence of more factors that may well interpret the volatility of ethanol prices.

The next step involves the impulse response analysis.

According to the results of the impulse response analysis as presented in Fig. 5, it is evident that factors leading to a change of one standard deviation for the crude oil price lead the prices of all other energy sources to a similar volatility pattern within a 10-month time period.

A one sd change in the GHG emissions presents the following results: an initial reduction in crude oil prices that becomes more intense after the third period. Furthermore, the same volatility pattern is evident for the two other energy prices. To be more specific, within the first time period an increase in the gasoline and ethanol price can be seen while after the fourth period the pattern alters utterly. Actually, ethanol prices are still increasing, while gasoline prices begin to decrease. A convergence in the aforementioned energy prices can be seen as we reach the last reference period. There is no specific pattern for the changes in the values of the other three variables when a one sd change occurs in the ethanol prices. Last but not least is the one sd change in the gasoline prices leading to the same pattern of change for all the other variables employed.

5. Conclusions

The present paper makes an effort to detect interlinkages among different energy prices. The particular study employs conventional (crude oil, gasoline prices) and renewable prices (ethanol prices). The crude oil prices according to our findings are not affected by the other energy prices and the gas emissions. As confirmed by a survey of European Central bank the increases of the crude oil prices may be attributed to factors other than demand and supply like speculations about future oil market conditions, as expressed by a shift in the future markets, or changes in the refining sector (i.e. a drop in the refinery utilization rate). The use of ethanol provides an incentive to use alternative energy sources in order to reduce the dependence on fossil fuels. It is an issue of great importance for policy makers and society apart from high energy prices and their consequences, to be concerned about the relevant volatility in crude oil prices that may well cause price spikes that are likely to harm the economy. Highly volatile crude oil prices or gasoline prices reduce crude oil or gasoline competitiveness respectively and represent a further incentive to adopt alternative energy sources [54,55]. Since currently ethanol is mainly produced from food crops, the upward shift in ethanol demand has also increased social and political concerns on the effects of this shift on both food price levels and volatility. This result implies that the formation of ethanol prices given that is produced by products and also used for food should internalize the risks arising from this fact as well as from changes in land use.

To be more specific the policy measures taken should balance the increasing necessity for the use of ethanol in order to satisfy energy needs, while on the other hand to achieve an efficient land distribution for energy and food cultivations.

In conclusion and based on the results of the present manuscript we may conclude the existence of interlinkages among the energy prices while the GHG emissions seem to affect the ethanol price in a significant way. This result may be of great importance for policy makers in order to promote the use of ethanol as a substitute to conventional energy source. Actually, understanding volatility transmission over time and across markets is important for both market participants, who will adjust their investment and hedging decisions accordingly, as well as for policy makers who are more concerned about the macroeconomic and social welfare consequences of the aforementioned price links.

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